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SPEED AND ACCURACY OF POSITIONING WEIGHTLESS OBJECTS AS A FUNCTION OF MASS, DISTANCE, AND DIRECTION

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WRIGHT AIR DEVELOPMENT DIVISION
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UNITED STATES AIR FORCE
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NOTICES

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Project No. 7184
Task No. 71586

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FOREWORD

This report was prepared by the Maintenance Design Section, Engineering Psychology Branch, Behavioral Sciences Laboratory, under Project 7184, "Human Factors in Advanced Flight," Task 71586, "Design Criteria for Ease of Maintenance." (A2C) William N. Kama was the project scientist. The author is indebted to the following members of the Maintenance Design Section for their contributions toward the preparation of the manuscript: Major Leroy D. Pigg, Section Chief, Captain James E. Wade, and Billy M. Crawford.

ABSTRACT

Human performance in positioning "weightless" objects was investigated experimentally using an air-bearing "frictionless" table. The subjects moved each of four masses (1000, 3000, 5000, and 7000 gram) various distances (10, 20, and 40 cm) in each of two directions over this frictionless table in response to paired light stimuli. The responses were accomplished in complete darkness after the lights were extinguished. Results were analyzed in terms of constant and absolute errors of positioning, and response time. From the investigation, we concluded that:

1. Mass has little effect on the accuracy of positioning. There is some evidence, however, that response time increases with increase in mass.

2. Distance is a significant variable affecting the direction of error, accuracy, and speed of positioning responses. Response time increases and accuracy decreases with distance.

3. Direction of movement is a significant variable affecting constant error, absolute error, and speed of positioning responses. Subjects tend to undershoot the mark in near to far movements.

PUBLICATION REVIEW

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SPEED AND ACCURACY OF POSITIONING WEIGHTLESS OBJECTS AS A FUNCTION OF MASS, DISTANCE, AND DIRECTION

INTRODUCTION

Weightlessness is one of many conditions that will affect man in the space environment. Just what effect this condition will have on the human body and on human performance, particularly after prolonged exposure, is still unknown. The Aerospace Medical Laboratory has conducted several studies of human performance in the weightlessness environment obtained in a C-131 aircraft flying a Keplerian trajectory. The periods of weightlessness thus obtained, however, are too short (13 to 15 seconds) for study of more than transient exposure effects.

In order to further the investigation of certain aspects of the weightlessness phenomenon, various "frictionless devices" have been developed. Utilizing compressed air, these devices operate with so little friction that the frictionless character of weightlessness is effectively simulated. One of these devices was used in this investigation of the speed and accuracy of human subjects in positioning objects of varying mass without the cues of weight and friction. The intent of this study was to determine the effect on human performance of the loss of these cues under space flight.

This problem becomes particularly important when work being done in the space environment involves the moving of objects from one position to another. For example, in moving a piece of equipment, the man must be able to stop it at the intended point before it causes damage or it is damaged by crashing into other equipment.

Efficiency of maintenance work may also be related to speed and accuracy of positioning movements. In making repairs, the maintenance man must be able to use his tools efficiently. If weightlessness affects his ability to position tools or other objects accurately, then making repairs can be a difficult process for him. Replacement of units such as console modules may be necessary, and any loss of normal positioning ability may prove costly in terms of damage to the equipment.

Several studies on man's positioning ability under normal friction and gravity conditions are reported in the literature. Principal among these investigations are those by Brown, Knauft, and Rosenbaum (ref. 1), State University of Iowa, who studied the ability of subjects to reproduce, by moving a pointer in the dark, a distance which they had perceived for a short interval. They found a tendency for subjects to overshoot the intended mark at the shorter distances (0.6 and 2.5 cm) and to fall short of the mark at the longer distances (10 and 40 cm). They also found that variability increased as distance to be moved increased.

In a subsequent study (ref. 2), Brown, Weiban, and Noriss found that near to far movements were faster than left to right movements, but that accuracy was greater for left to right movements at the longer distances. Accuracy was about the same for the left to right and the near to far movements at the shorter distances.

Spragg, Devoe, and Davidson also did some studies in accuracy of movements. In one study (ref. 3), they investigated the ability of subjects to duplicate horizontal movements by moving a metal rider back and forth on two horizontal metal rods while blindfolded. Their results confirmed, to some extent, the results of Brown, et al (ref. 1); they found that variability increased as distance increased. They also found that relative error decreased as movement distance increased.

The Brown and Spragg studies were carried out in the normal 1g environment conditions. In the present study the subjects were in the normal 1g environment, but the various masses which they were required to position were essentially weightless (i.e., supported by compressed air) and frictionless. The results, then, should provide information for the prediction of the effect of weightlessness on man's ability to position objects in the space environment.

METHOD

Apparatus

The apparatus consisted of three main pieces of equipment on a wooden table: (1) the stimulus light panel, (2) the subject's response platform, and (3) a cylindrical capsule in which weights of appropriate amounts were placed (figure 1).

The stimulus panel used to present the different distances to the subject consisted of a plywood panel 75 cm long by 17 cm high by 10 cm deep, painted a flat black, and containing thirteen 6-watt lights, 5 cm apart. Located on the top of the panel was a meter stick used with a sliding "T-square" for measurement of actual distances involved in positioning responses.

The subject's response platform consisted of a rectangular chamber 75 cm long by 25 cm wide by 7 cm high, set in front of the stimulus panel. This platform was made of two aluminum plates fastened together so as to form a chamber. The top plate was hollowed out and then perforated with 260 holes, each 0.04 mm in diameter. The bottom plate had a 1.25-cm hole through which compressed air was delivered to maintain a pressure of between 12 to 15 psi within the chamber. Air escaping through the holes in the top plate provided a "cushion" of air over which the capsule described below was literally airborne. Weight and friction were thus effectively eliminated as cues relating to movement of the capsule.

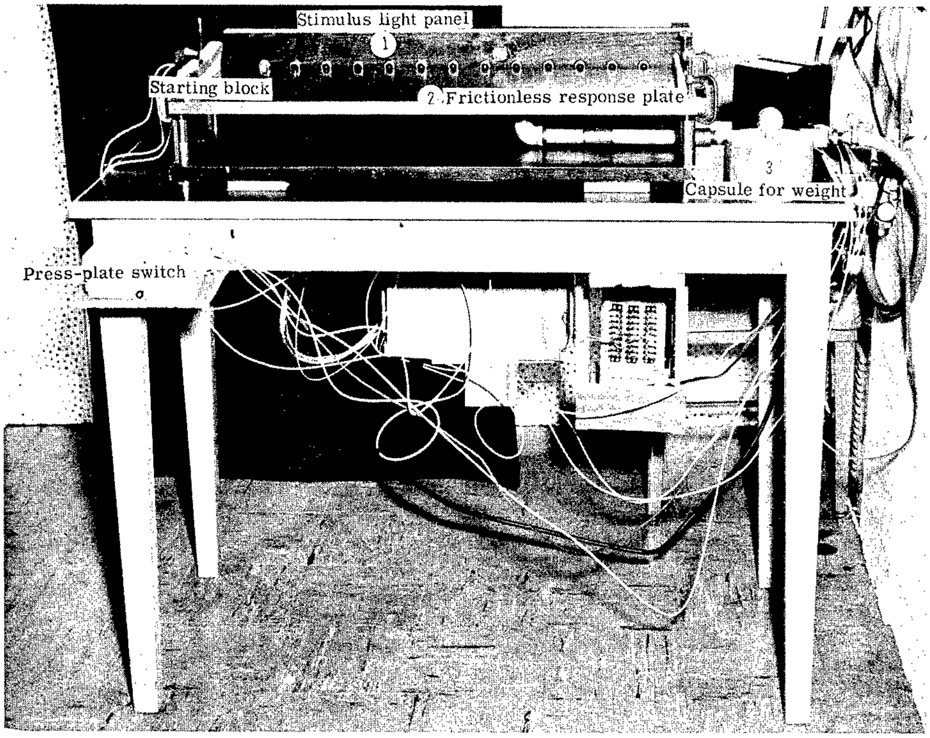

Figure 1. Experimental Apparatus

A cylindrical capsule, 12.5 cm in diameter and 7 cm high, with a removable cover and knob-handle was used to (1) house and support the different weights, which were used in conjunction with the capsule to form the test masses, and (2) eliminate differential visual and tactual cues to weight. The capsule weighed 750 grams; the four weights were of appropriate magnitudes so that when placed in the capsule, test masses of 1000, 3000, 5000, and 7000 grams were obtained. Figure 2 shows the capsule and the four metal weights used in the study.

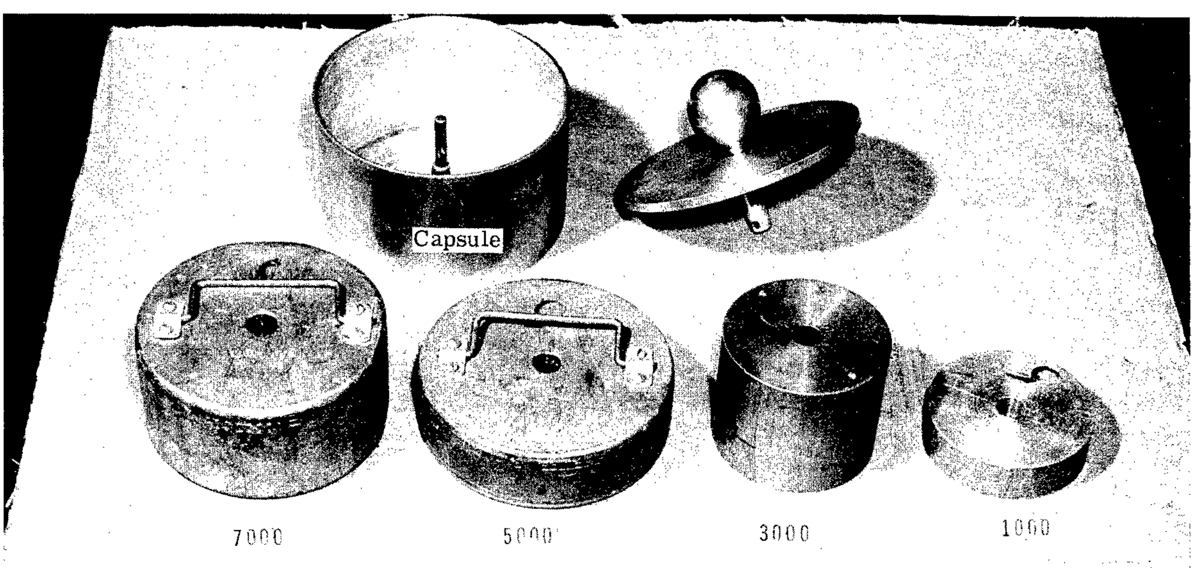

Figure 2. The Capsule and Four Weights Used in the Study

A starting block (figure 1) with an attached microswitch was located at the left of the response platform. Before each trial, the subject held the capsule against the starting block and microswitch. On the left end of the table on which the response platform and the stimulus panel were located was a press-plate switch which was used by the subjects to signal the end of a trial (figure 1). Operation of this switch diverted the air flow and caused immediate grounding of the capsule.

The experimenter's equipment consisted of a switch panel containing one master switch and thirteen light switches, by which he could turn on any of the three pairs of lights on the subject's stimulus panel. A Hunter timer, placed in the circuit for the lights, was used to turn off the stimulus lights after an interval of 2.5 seconds. A standard timer was used to record the subject's response time from the moment the capsule was moved away from the starting block microswitch to the moment the subject pressed the press-plate switch. This equipment is shown in figure 3.

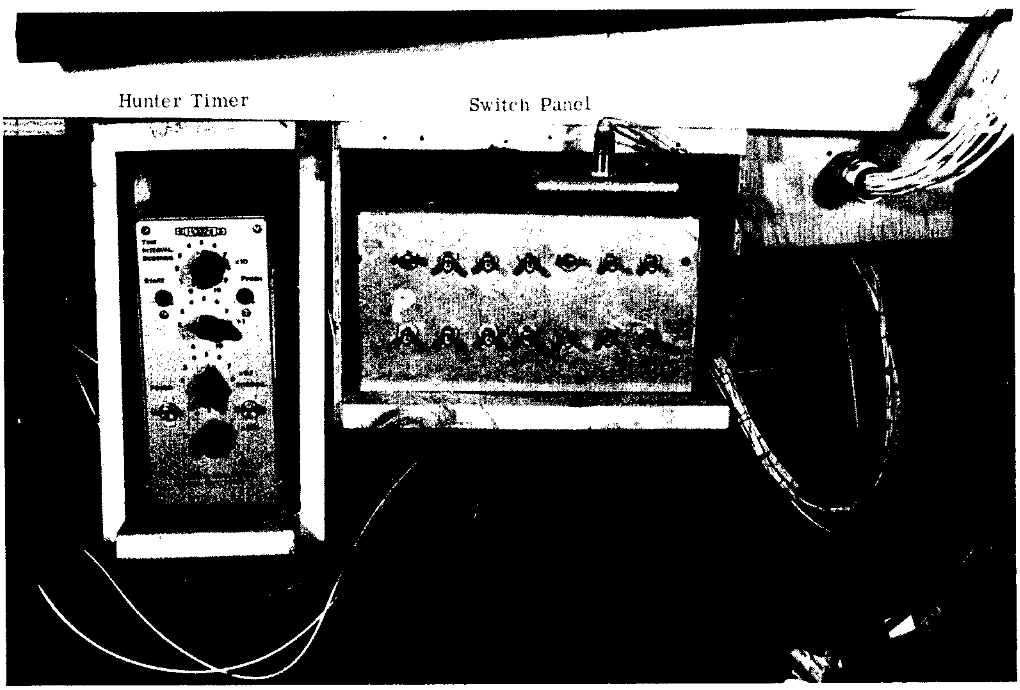

Figure 3. Experimenters Equipment Showing Hunter Timer and Stimulus Light Switches

Procedure

The experiment required that human subjects move four different masses (1000, 3000, 5000, and 7000 grams) three distances (10, 20, and 40 cm) in each of two horizontal directions. The distances to be moved were indicated by means of small lights mounted on a panel to the rear of the table. The positioning of the masses was accomplished in complete darkness after the cue for distance was given by means of appropriately paired lights.

Two experimental conditions were used: For condition 1, the subject stood in front of the table and made positioning movements in a horizontal plane from his left to his right; for condition 2, the subject stood at the left end of the table and made positioning movements forward from the front of the body. In each of these conditions, all combinations of the four masses (1000, 3000, 5000, and 7000 grams) and the three movement distances (10, 20, and 40 cm) were used for each subject.

The 24 subjects were undergraduate, male university students with a mean age of 22 years. Each subject was brought into the experimental room, a soundproof booth approximately 7 feet square, and placed in a standing position at the stimulus panel and response platform. He was then informed concerning the correct procedure for grasping the capsule with his right hand and operating the press-plate switch with his left hand. The following instructions were then read to the subject by the experimenter:

> *In a few minutes, I shall turn off the overhead light. Shortly after the light goes out, you will see two lights --a white one and a red one--light up on the panel in front of you. These two lights will remain on for a very short interval. During this interval, I want you to concentrate on the distance between these two lights.*
>
> *Immediately after the two lights go out, I want you to move the capsule until you feel that the knob of the capsule is directly in line with the red light that was on. (Demonstrate) When you think that you have reached this position, hold the capsule there and place your left hand on the switch plate located on the left end of the table. (Point out switch and have subject try it.) Do not disturb the capsule or move it back to the starting block until I tell you to do so. Are there any questions?*

Each subject made 15 consecutive reactions with each of the four masses to random presentations of the three distances. Each stimulus distance (distance between two lights) was presented visually for 2.5 seconds prior to each of the reactions. A total of 120 trials was given to each subject, 60 trials for the left-to-right movements and 60 trials for the near-to-far movements. Each trial consisted of the subject moving the capsule away from the starting block (this started a timer) to the desired position and depressing the press-plate switch which stopped the timer, grounded the capsule (by diverting the air-supply), and turned on an overhead light. A trial took between 30 to 45 seconds. After the first 60 trials, the subject was given a 10-minute rest period. When the subject returned to the experimental booth, the following instructions were read to him:

> *In this part of the experiment, I want you to do essentially the same thing as you did in the first part. However, you will now move the capsule in an outward (left-right) direction. Any questions?*

The subject was then given 60 more trials.

All trials were randomized and counter-balanced in order to combat the possibility of systematic errors.

RESULTS

The subjects' responses were recorded in terms of the algebraic difference in centimeters between the stimulus distance and the actual distance the capsule was moved and in terms of the length of time from movement of the capsule away from the starting switch to the pressing of the press-plate switch.

The analysis of the responses was accomplished under the following measures: (1) Constant Error (CE), (2) Absolute Error (AE), and (3) Response Time (RT).

A. Constant Error (CE)

The constant error reveals the direction and extent of positioning errors of a single subject. It is found by subtracting the "aimed-for distance" (stimulus distance) from the actual distance moved for each response and taking the mean of these for a given subject in each response category. Thus, movements that were consistently greater than the standard distance would produce positive constant error, while movements that fell short of the distance would produce negative constant error.

In figure 4, mean constant errors have been plotted for each standard distance and each mass under the two experimental conditions. The most obvious result revealed by the curves is that in Condition 2 (where movements were made in a near-to-far direction), subjects fell short of the intended mark (negative CE s) for all three of the standard

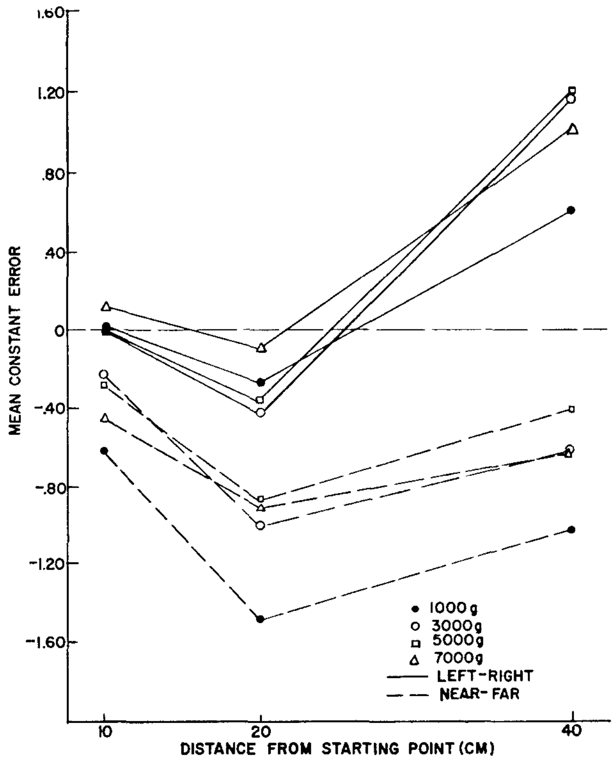

Figure 4. Direction of Error as a Function of Distance

distances and for all masses. In Condition 1 (where movements were made in the left-to-right direction), the results revealed no dominant trend at the 10-cm distance, but showed negative and positive constant errors at the 20- and 40-cm distances, respectively. It is worth noting that the form of the curves is the same for both near-to-far and left-to-right movements.

As is readily seen from inspection of the standard deviations of the CE s (table I), variability increased as movement distance increased. This was true for both the near-to-far and the left-to-right conditions.

TABLE I

TABLE OF MEAN CONSTANT ERRORS AND STANDARD DEVIATIONS

Condition	10 cm		20 cm		40 cm	
Left-Right	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1000	0.05	-0.58	-0.27	1.00	0.60	1.67
3000	0.00	0.69	-0.42	1.03	1.16	1.71
5000	-0.05	0.59	-0.36	0.89	1.20	1.63
7000	0.13	0.89	-0.11	1.10	1.01	1.43
Near-Far						
1000	-0.62	0.91	-1.38	1.55	-0.92	2.10
3000	-0.23	0.92	-1.00	1.44	-0.61	1.83
5000	-0.28	1.06	-0.86	1.44	-0.41	2.13
7000	-0.45	0.92	-0.91	1.33	-0.62	2.48

An analysis of the CE s by t-tests, comparing the various masses used in the study under the same conditions and at the same distances (table II), showed a significant difference (0. 5 level) between the 1000- and 5000-gram masses at the 10-cm distance for Condition 2. Results of other comparisons were not significant. Thus, it is apparent that change in mass had no general effect on CE.

Comparisons between distances, by mass and condition (table III), showed some systematic effects. Thus, for left-to-right movements, significant differences were found for 7 of the 12 distance comparisons. For the near-to-far movements, however, significant differences were found for only 2 of 12 comparisons. It is quite evident that distance had a more general effect on left-to-right movements than on near-to-far movements. A marked shift towards positive CE s (overshooting) occurred between the 20- and 40-cm distances for the left-to-right condition.

Comparison between conditions by mass and distance (table IV) produced the following results: at the 10-cm distance, two out of four comparisons were significant; at the 20-cm distance, three comparisons were significant; at the 40-cm distance, all differences were significant. All differences were in the same direction, i.e., toward undershoot for near-to-far movements by comparison with left-to-right movements. Thus, the performance in terms of CEs was obviously differentially affected by direction of movement response.

TABLE II

t's FOR MEAN CONSTANT ERRORS (BETWEEN MASSES)

	10 cm	20 cm	40 cm
Left-Right			
$t_{1000-3000}$	0.31	0.53	1.61
$t_{3000-5000}$	0.34	0.24	0.12
$t_{5000-7000}$	0.85	0.92	0.75
$t_{1000-5000}$	0.64	0.45	2.22*
$t_{3000-7000}$	0.61	1.02	1.64
$t_{1000-7000}$	0.40	0.60	0.45
Near-Far			
$t_{1000-3000}$	2.18*	1.32	0.62
$t_{3000-5000}$	0.22	0.48	0.41
$t_{5000-7000}$	0.88	0.19	0.44
$t_{1000-5000}$	1.38	1.52	0.99
$t_{3000-7000}$	1.03	0.30	0.01
$t_{1000-7000}$	0.73	1.21	0.53

* Significant to .05 level

TABLE III

t's FOR MEAN CONSTANT ERROR (BETWEEN DISTANCES)

	1000 g.	3000 g.	5000 g.	7000 g.
Left-Right				
t_{10-20}	0.91	1.50	1.41	0.80
t_{20-40}	1.49	2.97*	3.47*	2.51**
t_{10-40}	2.12**	3.78*	4.00*	3.02*
Near-Far				
t_{10-20}	2.27**	2.14**	1.57	1.00
t_{20-40}	0.81	0.91	0.26	0.31
t_{10-40}	0.84	0.83	0.83	0.30

* Significant to .01 level
** Significant to .05 level

TABLE IV

t's FOR MEAN CONSTANT ERRORS (BETWEEN CONDITIONS)

Left-Right	Near-Far	10 cm	20 cm	40 cm
t_{1000}	1000	3.72*	3.31*	2.50**
t_{3000}	3000	1.44	2.64**	4.06*
t_{5000}	5000	1.17	1.50	2.50**
t_{7000}	7000	3.04*	3.48*	2.77**

* Significant to .01 level
** Significant to .05 level

B. Absolute Error (AE)

The absolute error is a measure of performance that reveals the magnitude of the error made. It is obtained by subtracting the stimulus distance from the actual distance moved, without regard to whether the error is positive or negative. The results in terms of the absolute errors are found in table V and figure 5.

TABLE V

TABLE OF MEAN ABSOLUTE ERROR AND STANDARD DEVIATIONS

Conditions	10 cm		20 cm		40 cm	
Left-Right	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1000	0.79	0.35	1.29	0.60	1.76	1.21
3000	0.89	0.48	1.21	0.77	2.07	1.22
5000	0.98	0.50	1.15	0.57	1.92	1.22
7000	1.05	0.41	1.40	0.53	1.87	0.86
Near-Far						
1000	1.07	0.50	1.96	0.98	2.05	1.35
3000	1.11	0.49	1.75	1.05	1.98	1.01
5000	1.16	0.56	1.77	0.80	2.14	1.09
7000	1.09	0.49	1.61	0.81	2.37	1.35

Figure 5 shows the mean absolute errors for subjects using each mass under each condition. As shown by the curves, these errors increased as movement distance increased for both conditions. The errors for left-to-right movements were smaller than those for near-to-far movements, however, in all cases except one: this was at the 40-cm distance where left-to-right error for the 3000-gram mass was greater than the near-to-far error for both the 1000- and 3000-gram masses.

The variability of the absolute error, very much like that of the constant error, increased with increase in the distance moved. Also, as with constant error, absolute error was more variable for near-to-far movements than for left-to-right movements.

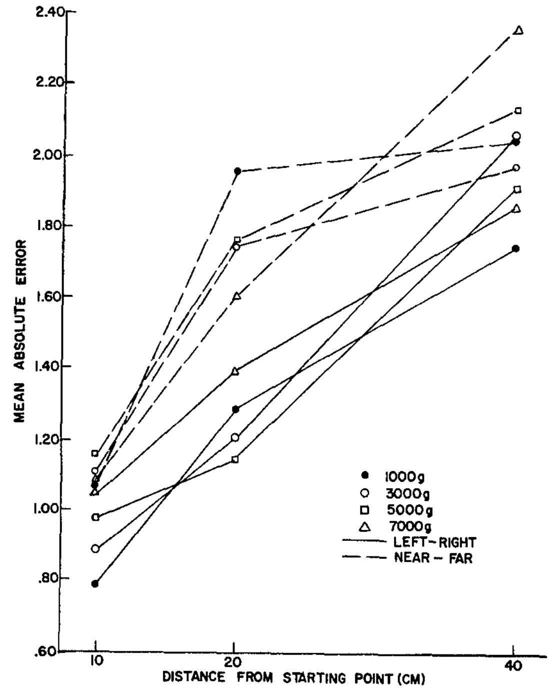

Figure 5. Accuracy of Movements as a Function of Distance

Analysis of the absolute errors by t-tests produced the following results. Tests between masses by condition and distance (table VI) revealed significant differences for only 3 of 36 possible comparisons. Since one out of 20 should have been significant at the 5 percent level by chance, even if there had been no difference, reliable evidence of an effect due to change in mass was not demonstrated. Thus, the results for absolute error agreed with those for constant error in showing no difference in performance with change in mass.

Comparisons between distances by condition and mass (table VII) showed the following results. For left-to-right movements, 9 of 12 comparisons were significant at either the .05 or .01 level. This was also true for near-to-far movements (9 out of 12 comparisons significant). Thus, generally significant differences in performance resulted from change in extent of positioning movements. All differences were in the same direction, i.e., absolute error increased with the increase in distance for both conditions.

Comparisons between conditions by mass and distance (table VIII) showed significant differences as follows: one out of 4 at the 10-cm distance, 3 out of 4 at the 20-cm distance, and 1 out of 4 at the 40-cm distance. These results offer evidence that there was a systematic difference between the two conditions. In all cases except one, the absolute error was larger for near-to-far than for left-to-right movements.

C. Response Time (RT)

Mean response times are presented in table IX and plotted graphically in figure 6. Figure 6 shows that response time increased as the movement distance increased. The results also show that response times for left-to-right movements were slightly but consistently longer than for near-to-far movements.

TABLE VI

t's FOR MEAN ABSOLUTE ERRORS (BETWEEN MASSES)

	10 cm	20 cm	40 cm
Left-Right			
$t_{1000-3000}$	0.83	0.42	1.29
$t_{3000-5000}$	0.60	0.29	0.60
$t_{5000-7000}$	0.54	2.08**	0.23
$t_{1000-5000}$	1.58	1.08	0.70
$t_{3000-7000}$	1.23	0.86	0.80
$t_{1000-7000}$	2.17**	0.65	0.58
Near-Far			
$t_{1000-3000}$	0.36	0.88	0.23
$t_{3000-5000}$	0.31	0.07	0.53
$t_{5000-7000}$	0.50	0.70	0.76
$t_{1000-5000}$	0.56	0.61	0.32
$t_{3000-7000}$	0.14	0.61	3.25*
$t_{1000-7000}$	0.15	1.59	1.00

* Significant to .01 level
** Significant to .05 level

TABLE VII

t's FOR THE MEAN ABSOLUTE ERROR (BETWEEN DISTANCES)

	1000 g.	3000 g.	5000 g.	7000 g.
Left-Right				
t_{10-20}	3.57*	1.77	1.06	2.50**
t_{20-40}	3.73*	4.37*	3.48*	4.10*
t_{10-40}	1.67	2.86*	2.75**	2.23**
Near-Far				
t_{10-20}	3.86*	2.66**	3.05*	2.60**
t_{20-40}	3.26*	3.78*	3.92*	4.26*
t_{10-40}	0.26	0.76	1.32	2.30**

* Significant to .01 level
** Significant to .05 level

TABLE VIII

t's FOR THE MEAN ABSOLUTE ERRORS (BETWEEN CONDITIONS)

Left-Right	Near-Far	10 cm	20 cm	40 cm
t_{1000}	1000	2.15**	2.79**	0.85
t_{3000}	3000	1.83	3.38*	0.30
t_{5000}	5000	1.29	3.44*	0.67
t_{7000}	7000	0.33	1.00	2.38**

* Significant to .01 level
** Significant to .05 level

TABLE IX

TABLE OF MEAN RESPONSE TIMES AND STANDARD DEVIATIONS

Condition	10 cm		20 cm		40 cm	
Left-Right	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1000	1.86	1.44	2.10	1.33	2.48	1.40
3000	1.83	1.23	2.18	1.25	2.62	1.29
5000	1.84	1.09	2.18	1.13	2.65	1.11
7000	1.99	1.18	2.35	1.32	2.90	1.44
Near-Far						
1000	1.49	0.88	1.70	1.04	1.99	1.01
3000	1.65	0.96	1.87	1.06	2.25	1.14
5000	1.54	0.94	1.86	1.04	2.37	1.29
7000	1.58	0.85	1.84	1.21	2.33	1.06

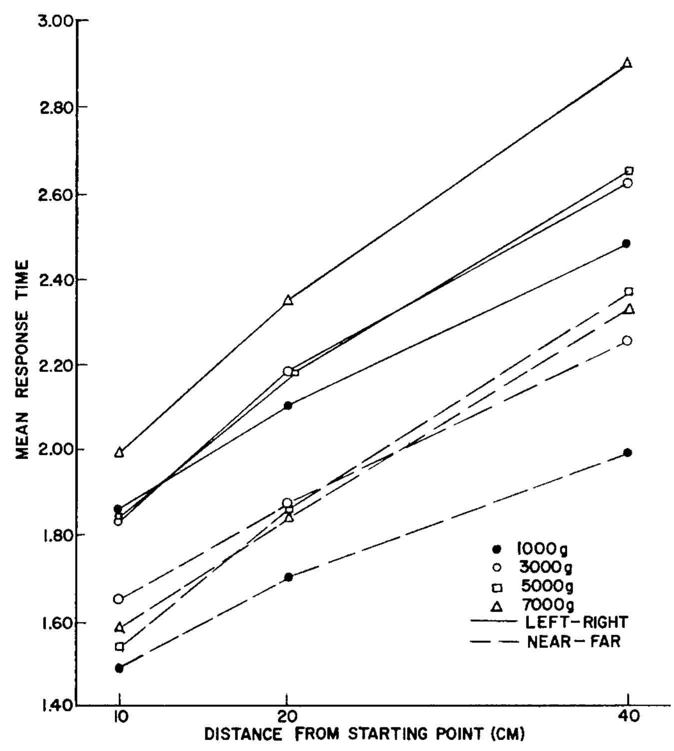

Figure 6. Speed of Movements as a Function of Distance

Statistical analysis of response times revealed evidence of a slight effect due to mass. Of the 36 comparisons between masses by condition and distance, 7 turned out to be significant at or beyond the .05 level (table X). For left-to-right movements, significance was found between the 1000- and 7000-gram masses and between 5000- and 7000-gram masses at the 20-cm distance, and between the 1000- and 7000-gram masses and the 3000- and 7000-gram masses at the 40-cm distance. For near-to-far movements, significant differences were found between the 1000- and 3000-gram masses at the 20-cm distance, and between the 1000- and 5000-gram masses and the 1000- and 7000-gram masses at the 40-cm distance. The direction of the significant differences was consistently towards longer response times for greater masses. Five of the significant comparisons were between the results with the 7000-gram mass and those with lesser masses. Another interesting observation is that all the significant differences occurred at the longer movement distances (20-and 40-cm).

TABLE X

t's FOR MEAN RESPONSE TIME (BETWEEN MASSES)

	10 cm	20 cm	40 cm
Left-Right			
$t_{1000-3000}$	0.34	1.00	1.75
$t_{3000-5000}$	0.08	0.00	0.20
$t_{5000-7000}$	1.50	2.13**	1.79
$t_{1000-5000}$	0.15	0.57	1.13
$t_{3000-7000}$	1.45	1.13	2.15**
$t_{1000-7000}$	1.30	2.08**	3.50*
Near-Far			
$t_{1000-3000}$	2.00	2.13**	2.00
$t_{3000-5000}$	1.00	0.08	0.67
$t_{5000-7000}$	0.50	0.25	0.33
$t_{1000-5000}$	0.63	1.33	2.53**
$t_{3000-7000}$	0.70	0.27	0.57
$t_{1000-7000}$	1.29	1.56	3.40*

* Significant to .01 level
** Significant to .05 level

Comparison of distances by mass and condition produced the following results. All 24 comparisons were found to be significant at or beyond the .05 level (table XI). Thus, distance had a systematic effect on time of positioning responses. Response times increased consistently and significantly as movement distance increased for both left-to-right and near-to-far movements.

TABLE XI

t's FOR MEAN RESPONSE TIME (BETWEEN DISTANCES)

Condition	1000 g.	3000 g.	5000 g.	7000 g.
Left-Right				
t_{10-20}	3.81*	4.54*	4.42*	3.30*
t_{20-40}	5.43*	6.98*	5.28*	6.18*
t_{10-40}	6.20*	8.88*	7.79*	7.22*
Near-Far				
t_{10-20}	2.72**	3.14*	5.08*	4.12*
t_{20-40}	4.14*	7.03*	5.43*	7.00*
t_{10-40}	5.62*	5.77*	6.59*	7.21*

* Significant to .01 level ** Significant to .05 level

When the two directions of movement were compared, 4 out of 12 t-values proved to be significant (table XII). These were found at the 10-cm distance for the 1000-gram mass, at the 20-cm distance for the 7000-gram mass, and at the 40-cm distance for the 1000- and 7000-gram masses. These results tend to verify that which is evident from inspection of the curves of figure 6: response times were consistently longer for left-to-right than for near-to-far movements.

TABLE XII

t's FOR MEAN RESPONSE TIME (BETWEEN CONDITIONS)

Left-Right	Near-Far	10 cm	20 cm	40 cm
t_{1000}	1000	2.47**	1.67	2.13**
t_{3000}	3000	0.69	1.29	1.37
t_{5000}	5000	1.58	1.78	1.47
t_{7000}	7000	1.95	2.83*	3.17*

* Significant to .01 level
** Significant to .05 level

DISCUSSION

The results of this study are similar to the results obtained by other investigations in this area. In terms of CEs, for example, it was found that subjects have a tendency to undershoot the intended mark. This tendency was also noted by Brown, et al (ref. 1), in their study.

The absolute error was found to increase as movement distance increased for both left-to-right and near-to-far movements, but left-to-right movements were consistently more accurate than near-to-far movements. Spragg, et al (ref. 3), also found a decrease in accuracy with distance for near-to-far movements.

Response times were 0.35 seconds faster on the average for near-to-far movements than for left-to-right movements. This is consistent with the finding of Brown, et al, (ref 2) that the time taken to complete an entire movement was longer under the left-right condition than under the near-far condition. Left-to-right movements were slower but more accurate, which is contrary to the generally accepted notion that speed and accuracy go together. The results are in agreement, however, with the findings of Woodworth as cited in Stevens (ref. 4). Woodworth found that accuracy was greater at slower speeds.

Variability of responses around both the mean constant error and the mean absolute error increased as movement distance increased. This tendency was also noted by Spragg, Brown, et al. The variability for left-to-right movements was less than that for near-to-far movements. Hypothetically, the difference between the two directions of movement was due primarily to two factors: type of movement involved (the left-to-right movement placed less restriction on adjustive corrections), and the angle from which the stimulus distances were viewed.

Change in the mass of an object had no pronounced effects on positioning responses. Tests of significance of effects of change in mass on direction of error and accuracy of positioning responses showed no significant trend. There was a slight tendency for response times to increase with increase in mass, especially at the longer movement distances. This suggests that differential effects of mass on positioning performance will be found, if at all, only for longer movements and with greater masses than were involved in this study.

Change in distance of positioning movement effected all of the measures of performance: constant error, absolute error, and response time. The effect on the direction of error (CE), however, was significant only where movements were in a left-right direction (table III). Since there is a greater restriction on the extent of positioning responses made from near-to-far, distance of movement of weightless objects appears to operate as a major variable affecting positioning performance.

The variable of direction of movement was also an important factor affecting general performance of positioning movements of weightless objects. Significant differences between left-to-right and near-to-far movements were noted on all three measures of performance. By comparison with left-to-right movements, near-to-far movements were faster but less accurate on the average and were more likely to stop short of the intended distance. Left-to-right movements, on the other hand, were more likely to overshoot at the 40-cm distance.

The results of this study cannot be taken as being conclusive for the handling of objects in the space environment, since the conditions under which it was carried out did not duplicate a true weightlessness situation. The objects handled were effectively weightless by virtue of having no friction. Thus, object inertia (function of mass) was the same as would be present in space, but there was freedom of movement within only the plane of the surface of the frictionless platform. This allowed 3 degrees of freedom, whereas in weightless space there would be 6 degrees of freedom of movement. Also, the subjects (and their arms) making the positioning responses were in the normal 1-g environment.

SUMMARY AND CONCLUSIONS

Human performance in positioning "weightlessness" objects was investigated experimentally using an air-bearing "frictionless" table to simulate the effect of weightlessness on object motion. The subjects moved each of four masses (100, 3000, 5000, and 7000 gram) various distances (10, 20, and 40 cm) in each of two directions over this frictionless table in response to paired light stimuli. The responses were accomplished in complete darkness after the lights were extinguished. Results were analyzed in terms of the constant error and absolute error of positioning, and response time. We concluded that:

1. Mass has little effect on the accuracy of positioning. There is some evidence, however, that response time increases with increase in mass.

2. Distance is a significant variable affecting the direction of error, accuracy, and speed of positioning responses. Response time increases and accuracy decreases with distance. Variability of responses also increases as distance increases.

3. Direction of movement is a signficant variable affecting constant error, absolute error, and speed of positioning responses. Subjects tend to undershoot the mark in near-to-far movements. Overshooting is detected at the 40-cm distance for left-to-right movements. Although response times are faster for near-to-far than for left-to-right movements, accuracy is greater for left-to-right than for the near-to-far movements.

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WADD TR 61-182
Aerospace Medical Laboratory, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.
SPEED AND ACCURACY OF POSITIONING WEIGHTLESS OBJECTS AS A FUNCTION OF MASS, DISTANCE, AND DIRECTION, by William N. Kama. 22 pp incl. illus., tables, 4 refs. March 1961. (Proj. 7184; Task 71586)
Unclassified report

Human performance in positioning "weightless" objects was investigated experimentally using an air-bearing "frictionless" table. The subjects moved each four masses (1000, 3000, 5000, and 7000 gram) various distances (10, 20, and 40 cm) in each of two directions over this frictionless table in response to paired

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